APPENDIX 10.B — MISCELLANEOUS

10.B.1 INTRODUCTION

This Appendix addresses the manual calculation of bridge backwater as presented in HDS 1 *(2)*. It also addresses the design of riprap at bridge abutments and piers as presented in HEC 11 (see Chapter 17).

The information presented in this Appendix covers the necessary calculations. The user should refer to the referenced publications for a more complete coverage of the subject.

10.B.1.1 Hydraulics of Bridge Waterways

10.B.1.1.1 Backwater

The expression for backwater has been formulated by applying the principle of conservation of energy between the point of maximum backwater upstream from the bridge, Section 1, and a point downstream from the bridge at which normal stage has been reestablished, Section 4 (Figure 10.B-1). The expression is reasonably valid if the channel in the vicinity of the bridge is essentially straight, the cross sectional area of the stream is fairly uniform, the gradient of the bottom is approximately constant between Sections 1 and 4, the flow is free to contract and expand, there is no appreciable scour of the bed in the constriction, and the flow is in the subcritical range.

The expression for computation of backwater upstream from a bridge constricting the flow is as follows:

$$h_1^* = K^* \alpha_2\ V_{n2}^2 / 2g + \alpha_1\ [(A_{n2} / A_4)^2 - (A_{n2} / A_1)^2]\ V_{n2}^2 / 2g$$

h_1^* = total backwater, ft
K^* = total backwater coefficient
α_1 & α_2 = as defined below
A_{n2} = gross water area in constriction measured below normal stage, ft^2
V_{n2} = average velocity in constriction* or Q/A_{n2}, ft/s
A_4 = water area at Section 4 where normal stage is reestablished, ft^2
A_1 = total water area at Section 1, including that produced by the backwater, ft^2

To compute backwater, it is necessary to obtain the approximate value of h_1^* by using the first part of the expression:

$$h_1^* = [(K^* \alpha_2\ (V_{n2}^2)] / 2g$$

The value of A_1 in the second part of expression, which depends on h_1^*, can then be determined and the second term of the expression evaluated:

$$\alpha_1\ [(A_{n2} / A_4)^2 - (A_{n2} / A_1)^2]\ V_{n2}^2 / 2g$$

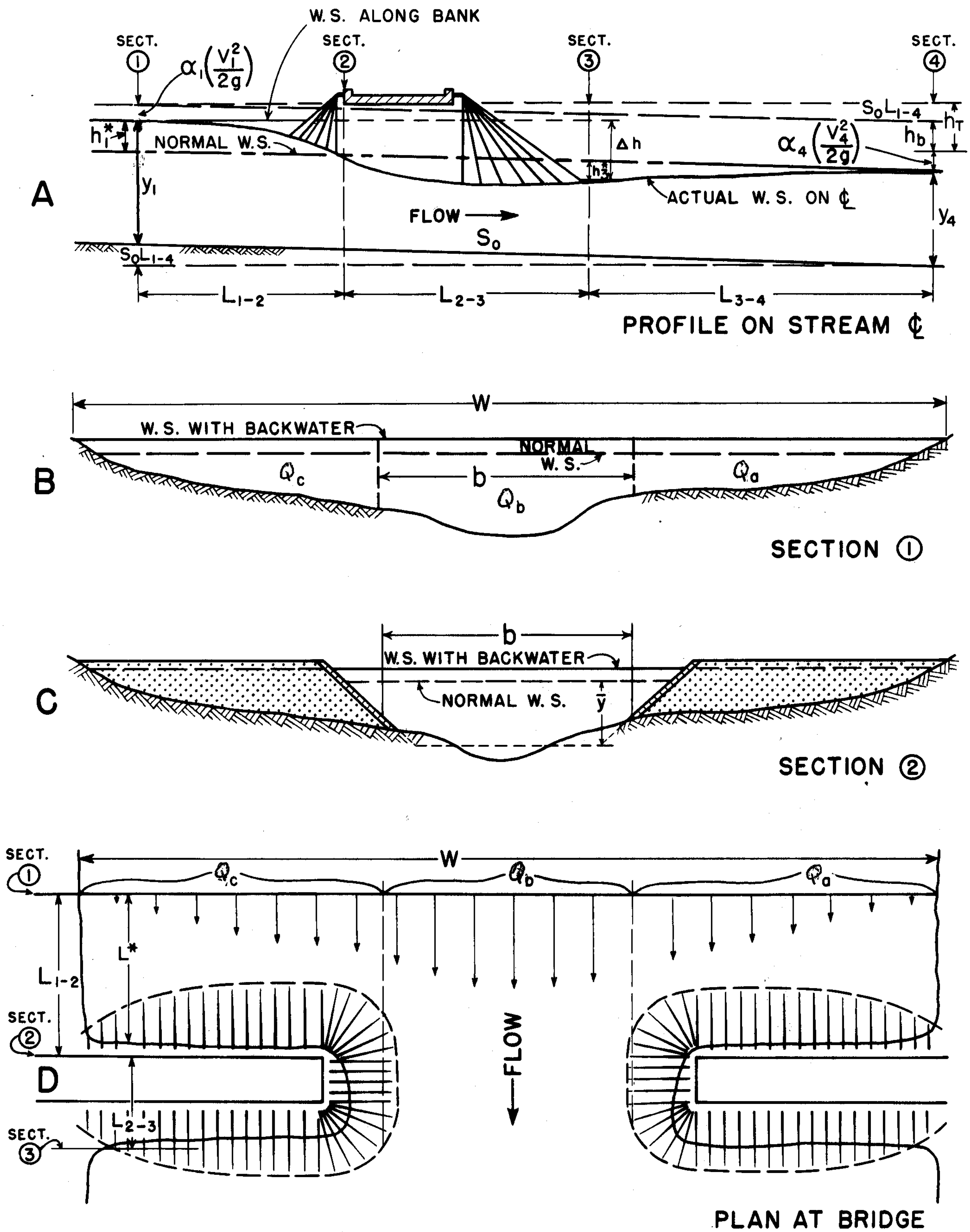

FIGURE 10.B-1 — Normal Crossing: Spillthrough Abutments *(2)*

This part of the expression represents the difference in kinetic energy between Sections 4 and 1, expressed in terms of the velocity head, $V_{n2}^2/2g$.

Bridge Opening Ratio:

$$M = Q_b/(Q_a + Q_b + Q_c)$$

Kinetic Energy Coefficient:

$$\alpha_1 = (qv^2)/QV_1^2$$

where:
- v = average velocity in a subsection
- q = discharge in same subsection
- Q = total discharge in river
- V_1 = average velocity in river at Section 1, or Q/A_1

Width of Constriction:

$b = A_{n2}/y$ (see Figure 10.B-1)

Backwater Coefficient:

$$K^* = K_b + \Delta K_p + \Delta K_s + \Delta K_e$$

where:
- K_b = base constriction coefficient
- ΔK_p = pier coefficient
- ΔK_s = skew coefficient
- ΔK_e = eccentricity coefficient

Individual coefficient values are obtained from figures in HDS 1.

10.B.1.1.2 Example

Find the Bridge Backwater caused by this roadway crossing:

Given:

The channel crossing is shown in Figure 10.B-2 with the following information: Cross section of river at bridge site (areas, wetted perimeters and values of Manning's n are given in Table 10.B-1); normal water surface for design = El 28.0 ft at bridge; average slope of river in vicinity of bridge is 0.00049 ft/ft; cross section under bridge showing area below normal water surface and width of roadway = 40 ft. The stream is essentially straight, the cross section relatively constant in the vicinity of the bridge, and the crossing is normal to the general direction of flow.

Solution:

Under the conditions stated, it is permissible to assume that the cross sectional area of the stream at Section 1 is the same as that at the bridge. The approach section is then divided into subsections at abrupt changes in depth or channel roughness as shown in Figure 10.B-2. The conveyance of each subsection is computed as shown in Columns 1 through 8 of Table 10.B-1. The summation of the individual values in Column 8 represents the overall conveyance of the stream at Section 1, or K_1 = 879 489. Note that the water interface between subsections is not

TABLE 10.B-1 — Calculation Summary

	1	2	3	4	5	6	7	8	9	10	11
	SUB-SECTION	n	$\frac{1.49}{n}$	A (ft^2)	P (ft)	$R=\frac{A}{P}$ (ft)	$R^{2/3}$	$k=\left(\frac{1.49}{n}\right)AR^{2/3}$	$q=Q\frac{k}{k_1}$ (ft^3/s)	$V=\frac{q}{A}$ (ft/s)	qV^2
Q_c	0-200	0.045	33.0	627.4	200.2	3.134	2.142	44,349	983.3	1.57	2,424
	200-240	0.070	21.2	285.2	40.1	7.112	3.698	22,359	495.7	1.74	1,501
Q_b	240-280	0.070	21.2	324.5	40.1	8.092	4.031	27,732	614.8	1.89	2,196
	280-420	0.035	42.5	2,004.0	145.0	13.821	5.759	490,492	10,875.2	5.43	320,654
	420-445	0.050	29.7	205.8	25.1	8.199	4.066	24,852	551.0	2.68	3,958
Q_a	445-500	0.050	29.7	539.4	55.1	9.789	4.576	73,309	1,625.4	3.01	14,726
	500-750	0.045	33.0	1,677.4	251.0	6.683	3.548	196,396	4,354.6	2.60	29,436
S_o = 0.00049				A_n = 5,663.7 ft^2				k_1 = 879,489	Q = 19,500.0 ft^3/s		ΣqV^2= 374,895
				An_2 = 2,534 ft^2					Q_b = 12,040 ft^3/s		

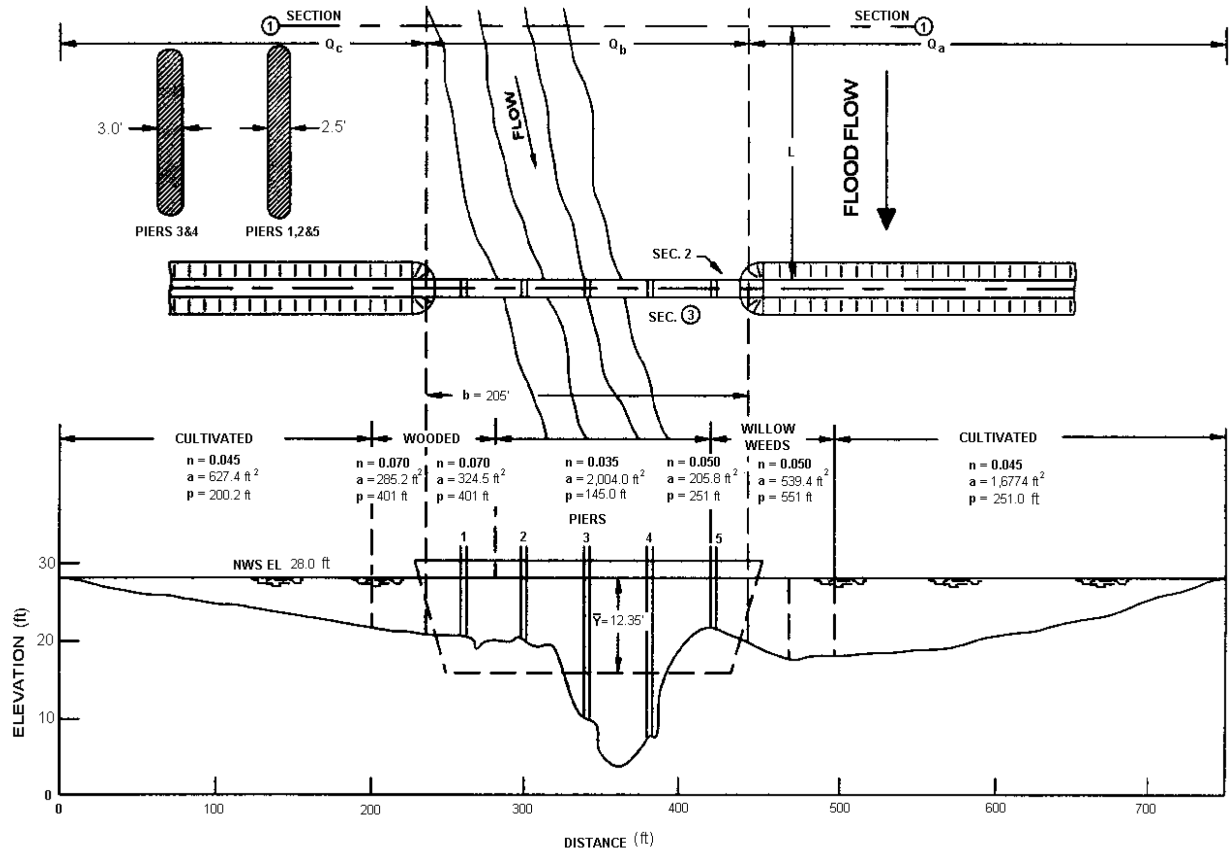

FIGURE 10.B-2 — Channel Crossing

included in the wetted perimeter. Table 10.B-1 is set up in short form to better demonstrate the method. The actual computation would involve many subsections corresponding to breaks in grade or changes in channel roughness.

Because the slope of the stream is known (2.6 ft/mi) and the cross sectional area is essentially constant throughout the reach under consideration, it is permissible to solve for the discharge by what is known as the slope-area method or:

$$Q = K_1 S_o^{1/2} = 879{,}489(0.00049)^{1/2} = 19{,}500 \text{ cfs}$$

To compute the kinetic energy coefficient, it is first necessary to complete Columns 9, 10 and 11 of Table 10.B-1; then:

$$\alpha_1 = \frac{qv^2}{QV_1^2} = \frac{374{,}895}{19{,}500(19{,}500/5{,}664)^2} = 1.62$$

The sum of the individual discharges in Column 9 must equal 19,500 ft^3/s. The factor M is the ratio of that portion of the discharge approaching the bridge in width, b, to the total discharge of the river:

$$M = Q \qquad M = Q_b / Q = 12{,}040/19{,}500 = 0.62$$

Entering Figure 5 in HDS 1 with $\alpha_1 = 1.62$ and M = 0.62, the value of α_2 is estimated as 1.40.

Entering Figure 6 in HDS 1 with M = 0.62, the base curve coefficient is K_b = 0.72 for a bridge waterway of 205 ft.

Because the bridge is supported by five solid piers, the incremental coefficient (ΔK_p) for this effect is determined. Referring to Figure 10.B-2 and Table 10.B-1, the gross water area under the bridge for normal stage, A_{n2}, is 2,534 ft^2, and the area obstructed by the piers, $A_{p,}$ is 180 ft^2; so:

$J = A_p/A_{n2}$ J = 180/2,534 = 0.071

Entering Figure 7A in HDS 1 with J = 0.071 for solid piers, the reading from the ordinate is ΔK = 0.13. This value is for M = 1.0. Now, enter Figure 7B in HDS 1 and obtain the correction factor σ, for M = 0.62, which is 0.84. The incremental backwater coefficient for the five piers, $\Delta K_p = \Delta K\sigma$ = (0.13)(0.84) = 0.11.

The overall backwater coefficient:

$K^* = K_b + \Delta K_p = 0.72 + 0.11 = 0.83,$

$$V_{n2} = \frac{Q}{A_{n2}} = \frac{19{,}500}{2{,}534} = 7.70 \text{ ft/s}$$

and

$$V_{n2}^2/2g = (7.70)^2/((2)(32.2)) = 0.92 \text{ ft}$$

The approximate backwater will be:

$$K^*\alpha_2(V_{n2}^2/2g) = (0.83)(1.40)(0.92) = 1.07 \text{ ft}$$

Substituting values in the second half of the expression for the difference in kinetic energy between Sections 4 and 1 where A_{n1} = 5,664 ft^2 = A_4:

A_1 = 6,384 ft^2 and A_{n2} = 2,534 ft^2

$$\alpha_1 \left[(A_{n2}/A_4)^2 - (A_{n2}/A_1)^2\right] V_{n2}^2/2g$$

= 1.62 [(2,534/5,664)^2 – (2,534/6,384)^2] (0.92)
= (1.62)(0.042)(0.92)
= 0.06 ft

Then, total backwater produced by the bridge is:

h_1^* = 1.07 + 0.06 = 1.13 ft

10.B.1.2 <u>Riprap At Piers and Abutments</u>

10.B.1.2.1 Abutments

The equation for determining the required size of riprap stone at abutments is:

$D_{50}/y = [K/S_S - 1)] (V^2/gy)$, in cases where the Froude Number $(V/(gy)^{1/2})$ is equal to or less than 0.8,

where:
- D_{50} = median stone diameter, ft
- V = characteristic average velocity in the contracted section (explained below), ft/s
- S_S = specific gravity of rock riprap (normally 2.65)
- g = gravitational acceleration, 32.2 ft/s^2
- y = depth of flow in the contracted bridge opening, ft
- K = 0.89 for a spill-through abutment and 1.02 for a vertical wall abutment

or

$D_{50}/y = [K/S_S - 1)] (V^2/gy)^{0.14}$, in cases where the Froude Number is greater than 0.8,

where: K = 0.61 for a spill-through abutment and 0.60 for a vertical abutment

10.B.1.2.2 Piers

Determine the D_{50} size of the riprap using the following equation to solve for stone diameter (in feet, for fresh water):

$$D_{50} = 0.692(KV)^2/[(S_S - 1)2g]$$

where:
- D_{50} = median stone diameter, ft
- K = coefficient for pier shape
- V = velocity at pier, ft/s
- S_S = specific gravity for riprap (normally 2.65)
- g = gravitational acceleration, 32.2 ft/s^2
- K = 1.5 for rounded-nose piers and 1.7 for rectangular piers

<u>Example</u>: V = 9.0 ft/s
K = 1.7 (rounded-nose pier)
$D_{50} = 0.692\,[1.7(9.0)]^2/[(2.65 - 1)(2)(32.2)]$
D_{50} = 1.52 ft, use 1.50 ft